University of Alberta Library
0 1620 3448538 1

For Reference

NOT TO BE TAKEN FROM THIS ROOM

Library of the University of Alberta, Edmonton, Alberta

Perrier, J.F.
A frequency measuring device

Thesis
1950
#36

Ex libris
universitatis
albertaensis

Digitized by the Internet Archive
in 2018 with funding from
University of Alberta Libraries

https://archive.org/details/frequencymeasuri00perr

A

FREQUENCY MEASURING

DEVICE

THE UNIVERSITY OF ALBERTA

A FREQUENCY MEASURING DEVICE

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE

FACULTY OF ENGINEERING

BY

J. F. PERRIER

EDMONTON, ALBERTA
APRIL, 1950.

INDEX

Page

1. Introduction 1

2. Block Diagram and Description 5

3. Development of Circuits 7

3.1 Choice of a vacuum tube for a bistable multivibrator 10
3.2 Selection of circuit parameters 13

4. Operation of a decade 17

5. Further considerations on decade developments 20
5.1 Tubes for HF operation 21
5.2 Feedback difficulties 23
5.3 Further possibilities 24

6. Description of other circuits 25
6.1 Broadband amplifier 25
6.2 Receiver 27
6.3 Power supply 27

7. Operation of units 28

8. Acknowledgement 29

9. References 31

1. INTRODUCTION

The subject of frequency measurement of electromagnetic waves or sound waves can be divided into two main problems. A standard which is analogous to the International yard or the International meter at Sevres, France is required and then equipment must be constructed and methods devised for comparing unknown frequencies to the above standard. Obviously the accuracy of our measurements can be no better than that of the standard.

The standard for the measurement of frequency of electromagnetic waves is called a primary frequency standard. In the Western Hemisphere, the staff of the United States Naval observatory uses the mean of a number of observations on the passages of stars to compute corrections for time signals which have been originally determined from the rotation of the earth. These time signals are used to check ~~h~~ the rates of the quartz-controlled oscillators maintained by the United States Bureau of Standards, one of which controls the signals emitted by Radio Station WWV. The published accuracy of WWV is one part in ten million. At present unpredictable changes of the order of 4 parts in 10^8 detected on rare occasions in the rotation of the earth seem to have set a limit to the use of the earth's rotation as a standard of frequency.[1] Recently the National Bureau of Standards has indicated that an "atomic clock"

may be a more reliable standard than the earth, and may eventually be chosen for the primary standard.

The practical problem of measurement of frequency then resolves itself into devising and constructing equipment whose frequency can be easily compared to the primary standard. Therefore, providing proper comparison methods are available, the accuracy of this equipment is the same as that of the primary standard. Such an assembly of equipment is called a secondary frequency standard.

Clearly, the methods of comparison between a secondary and the primary standard are of great importance. In this respect, methods have been developed which can compare frequencies accurately to the order of one ten-thousandth of a cycle per second,(2) and more recently to one part in 10^{11}(3). Frequency comparison methods are then more than adequate for the calibration of secondary frequency standards.

Depending on the range of frequencies to be measured, many methods of varying accuracy have been used in the secondary standard. Equipment useful in the range of 100 kc/s to 100 mc/s has been developed(4) using the principle of beats. If an unknown frequency is to be measured, it is mixed with a standard frequency and the resulting beat is measured by any one or combination of the following methods: zero-beat or null method, Lissajou figures, direct interpolation or sliding harmonics.(5) The resulting beat is then mixed with another standard frequency to produce a

second beat to be measured as before. This process is carried out until the desired accuracy is obtained.

With the advent of increasingly useful cathode ray oscilloscopes, and improved techniques in the production of pulses, a method of frequency measurement suggested itself to the writer. This involved taking a signal of unknown frequency, changing its form from a sinusoidal wave to sharp pulses of the same frequency and of the order of a microsecond wide and displaying these on a cathode ray tube. To carry out the measurement, a known frequency, pulse shaped as above, would be introduced on the screen which would allow the time between two successive pulses of the unknown frequency to be obtained. This measurement is the period of the wave and its reciprocal is the frequency. Such an observation could only be made to two significant figures or three at the very most. Greater accuracy would be obtained by beating the unknown sinusoid with a standard sinusoid, and a second measurement as outlined above would be repeated. This process would be repeated till the desired accuracy was obtained. See Fig. 1 for a possible arrangement to incorporate this method.

A second method, suggested by Prof. Porteous, involved the counting of the cycles or pulses produced from the original sinusoids for a period of one second. The

problem of counting automatically suggested the use of a bi-stable multivibrator originally called the Eccles-Jordan trigger circuit and developed in 1919. Until recent years this circuit had not found much use but the pulse technique requirements have brought it to the fore. Radiation counters in conjunction with Geiger-Muller tubes have been constructed to incorporate such circuits. Briefly, the bi-stable multivibrator is an electronic circuit having two stable terminus conditions. On the application of a pulse of electrical energy to a suitable point in the circuit, the terminus condition is shifted. On the application of a second pulse at the same point, the terminus condition is brought back to its original position. Due to the nature of the circuit, the operation can be considered as a division by two. In other words, for every two pulses introduced into the circuit, only one pulse will be present in the output. Clearly then, two of these stages may be interpreted as division by four. Extending this principle we have at our disposal a binary system of counting. If now, pulses representing the unknown frequency are introduced to our binary counter for a period of one second, a proper analysis of the terminus conditions of each of the binary counters will indicate the number of counts received in one second. This is frequency.

2. BLOCK DIAGRAM AND DESCRIPTION

Fig. 2 shows a block diagram of the circuits involved in the design of a binary counter.

An unknown signal represented by a sinusoidal wave is introduced into the broad-band or video amplifier whose passband is twenty cycles per second to twelve megacycles per second. Its function is to amplify the incoming signal to such a point that the amplifier "blocks" - i.e., the input wave is successively "clipped" in the various stages to produce square waves. These square Waves are then fed to the "one second gate" which is simply an amplifier whose screen voltage can be controlled to give either full conduction or complete blocking.

The signals passed by the gate are fed to a pulse standardizer whose sole function is to produce pulses of constant width and constant height and for frequencies below 300 kc/s this pulse standardizer may be a mono-stable multivibrator (one-shot multivibrator) or a blocking oscillator for frequencies above this. The output pulses are then fed to a decade D_7 as shown in Fig. 2.

A decade is a particular arrangement of bi-stable multivibrators whose function is to produce one output pulse for every ten introduced to the circuit. The powers of ten shown in Fig. 2 indicate the highest frequency to be handled by each decade. The output of D_7 which is a sequence of

pulses occuring at a pulse repetition frequency of 10^6 is fed to decade D_8 which in turn divides the input pulses by ten. Seven such decades are included to obtain a measurement accurate to seven significant figures at ten megacycles.

At the end of one second the gate closes and the positions or states of the various decades is shown on the indicator unit. If, before the counting process is started, all the decades have been set to an arbitrary zero, then the reading of the indicator unit will be the frequency.

The remainder of the circuit is used in conjunction with the gate. A highly stabilized oscillator of the bridge type (6) produces oscillations at a frequency of 100 Kc/s and after having been fed to a buffer or isolating amplifier, the output is split into two portions. Part of the output is taken to a frequency multiplier, where it is multiplied by a factor of one hundred. The resultant 10 megacycle per second signal is introduced to a fixed frequency receiver tuned to Radio Station WWV on 10 mc/s. With the aid of a small tuning condenser placed across the crystal the frequency of the oscillator circuit may be synchronized to the primary standard. Assuming the choice of a proper method the crystal frequency can be compared to WWV to within one cycle per second. We can then say that the accuracy is one part in ten million or in other words, the crystal frequency is accurate to 0.01 of a cycle at 100kc/s.

The other portion of the output of the isolating buffer is taken to a number of decades, D_1 D_2.............. After successive divisions by ten, the output of D_5 is at a pulse repetition frequency of one cycle per second without having impaired the above accuracy. This is the signal that is used to operate the "one-second" gate.

If greater accuracy at low frequencies is desired another decade D_6 has been added to extend the counting period to 10 secs. The decimal point associated with the indicator unit would have to be adjusted accordingly.

3. DEVELOPMENT OF CIRCUITS

The basic unit which had to be developed was the decade unit. Originally, it was intended to use a decade developed along lines suggested by Regener (7,9,9). This decade was composed of five pairs of pentodes together with ten double triodes arranged in the form of a circle. Each triggering pair was a modification of the original Eccles-Jordan circuit. However the cost of such a construction would be prohibitive since at least ten decades would be required. It is noted here that an attractive feature of the Regener decade was the fact that it could be triggered with sine waves if necessary.

Further investigation lead to the adoption of the decade using bistable multivibrators with feedback. Such a decade has been described by Grosdoff (11) and again by Bliss (12).

Since no values were given for the circuit parameters it was necessary to develop this circuit.

The basic circuit for the bistable multivibrator is indicated in Fig. 3. It is noted here that circuits of this type have also been called "scaling" circuits, "scale-of-two" circuits, "flip-flop" circuits and in England "lock-over" circuits. The term bistable multivibrator will be used here and will henceforth be ~~a~~ abbreviated BM.

Due to the circuit arrangement of the cross-coupling between plates and grids, the system will be stable only when one section is conducting and the other one is cut off. If the right-hand triode V_2 is conducting or on, then its plate, (point A in the circuit) will be at a relatively low potential, while the plate of V_1 will be high due to non-conduction. Point A being low will allow point B which is the grid connection to V_1 to be low enough in potential to produce cut off in V_1. At the same time point D is held relatively high because C is high, and since D is connected to the grid of triode V_2, conduction will take place. In a well designed circuit this condition is very stable, since V_1 is biased well beyong cut off and V_2 is held conducting with its grid either slightly positive or slightly negative. Since the circuit is symmetrical, the other mode or state, with V_1 on and V_2 off, is equally stable.

Assuming again the initial condition of V_1 off and V_2 on, the action when an input driving pulse is applied will be investigated. A negative polarity pulse is applied through capacitor C_2 to the common plate-circuit resistor R. Some of the pulse energy will travel through the right hand plate resistor R_1, and be dissipated largely in the low impedance of V_2. Part of it may reach the grid of V_1, by way of the right hand C_1, but no action results from this since V_1, is cut off. A second portion of the pulse energy will find its way to the grid of V_2 by way of R_1 and C_1 on the left side. The resulting negative swing in this grid voltage causes a reduction in plate current in V_2 and raises its plate potential slightly. This increase in plate potential drives the grid of V_1 in the positive direction to start conduction through it. This initiates a drop in plate potential of C which is transferred to D to reinforce the effect of the negative driving pulse. This loop feedback drive is highly cumulative and the circuit very quickly triggers over to its other stable state with V_1 on and V_2 off.

In a similar manner the next applied negative input pulse will return the circuit to the starting point. In practical use a reset switch may be connected as shown to open the bias lead. This causes V_2 to go on (if it is not already on) and insures that the circuit is returned to a standard starting condition. An output connection for a succeeding stage may be taken from A. The input capacitor of this next stage will differentiate the output of V_2 to

give negative and positive pulses. Since a given stage responds only to negative pulses there is a division by two in each BM.

The stages following one another will have four states, i.e., any given configuration of states will be repeated for every four pulses that are fed to the first stage. This can be interpreted then as division by four. Obviously the length of binary chain can be extended to have as great a capacity (number of states) as desired. The capacity then equals 2^r where r is the number of states.

3.1 CHOICE OF VACUUM TUBE FOR A BISTABLE MULTIVIBRATOR

The choice of a vacuum tube for V_1 and V_2 obviously leads to the double triode and in order to save as much space as possible, a miniature type would be preferable. No simple criterion relating the tube characteristics to the particular circuit can be found which will narrow the field of selection to one or two choices. Since the upper frequency limit was much higher than could be handled by any BM in the literature, it was imperative that the best tube available should be selected at the very outset. An analysis stated by Bliss(12) was found to be of some help and it will be given here to provide continuity.

"As a first step in analyzing the problem, the circuit for one section or one-half of a binary stage may be reduced to the equivalent circuit of Figure 4. In this diagram C_t represents the equivalent total plate-to-ground capacity in the circuit. This includes not only the coupling and output drive capacity but also the stray and internal tube capacity. R_p is the dynamic internal plate-to-cathode resistance of the tube. Since electron transit time is not the first speed limitation encountered, the dynamic action of the tube may be represented approximately by the switch K. The condition for cutoff is with K open, and for conduction with K closed.

"For high-speed performance, it is necessary that the swings in potential of point E, as the switch is operated, take place as rapidly as possible. For given values of R_L and R_p, the speed of response is limited by the size of C_t. When the switch is opened, C_t charges through R_L, and when the switch is closed, it discharges through R_p. Obviously all three of these circuit elements should be as small as possible if the highest speed of operation is desired.

"Although other considerations are involved, the value of R_L usually can be made as low as R_p. The ultimate speed of this circuit is then dependent on R_p and C_t and it is inversely proportional to their product. This condition may be expressed as

$$S = \frac{K}{R_p C_T} \qquad (1)$$

where S is the speed in some chosen unit, K is a unit conversion factor, and R_p and C_t are as indicated in the diagram in Figure 4.

"Although C_t includes external as well as internal capacitance, it still remains that the maximum obtainable speed depends primarily on characteristics of the tube. The foregoing expression may be modified somewhat to give a better factor of merit. Since the value of R_p depends mostly on how much current the tube will pass without injury, and this current is inversely proportional to R_p for a given voltage, the formula may be rewritten as

$$S = \frac{K I_T}{C_T} \qquad (2)$$

"If I_t (the tube current) is expressed in milliamperes, K is equal to unity, and C_t is expressed in micromicrofarads, then S is the factor of merit in milliamperes per micromicrofarad. In other words, this formula states that a tube suitable for high-speed operation should be able to handle as much current as possible with as low an output capacitance as possible or more strictly speaking, the ratio of current to capacitance should be high. It is interesting to note that equation (2) obtained by simple deduction is also the equation for the maximum possible rate of voltage build-up for the conditions indicated.

[illegible]

[illegible]

[illegible]

[illegible]

"Although this expression is the primary criterion to use in high-speed design, there are other factors to be considered. The tube also should have a high value of grid-to-plate mutual transconductance so that changes in plate voltage will produce sufficient changes in the opposite grid voltage to insure switch-like operation. Although R_L would be made comparable to R_p in value, too low a plate resistor would develop too low a plate voltage swing for good utilization. It should be remembered also that C_t includes all the plate-circuit output capacity and not that of the tube alone."

In view of the above as well as from a consideration of economy the miniature type 6J6 was finally chosen. It is noted here that a criterion applicable for selection of vacuum tubes for a-stable multivibrators (free-running) as mentioned in the literature (14) produced a result which was in keeping with the above.

3.2 SELECTION OF CIRCUIT PARAMETERS

As a first attempt to select the circuit parameters from an analysis, the circuit shown in Fig. 5 was used. It is drawn to correspond to Fig. 3 and it is assumed that V_1 is on. This is an analysis of the steady state or terminus conditions. For this circuit we can write: -

$$E_{cc} = R_3 (i_2 - i_c)$$

$$E_{bb} = i_2 (R_1 + R_2)$$

$$E_{bb} = i_1 R_1 + e_{b_1}$$

$$E_{cc} = -e_{b_1} + (i_1 - i_b)(R_2 + R_3)$$

$$E_{cc} = (i_1 - i_b) R_3 + K_{co}$$

where Kco is the extra voltage beyond cut off for the non-conducting tube.

The above equations together with the tube characteristics are not sufficient in themselves to determine fully any one particular circuit. There are too many variables and not enough equations, and therefore some of the variables must be arbitrarily chosen. For this reason a number of conditions can be suitably imposed on the BM at this point. As outlined above the series plate resistance must be relatively low - i.e., not more than two or three times the plate resistance of the tube for the zero bias condition. Also from the same

considerations, the plate current must be high. The only limitation here is the plate dissipation of the tube. Further, the difference in plate voltages ($e_{b1} - e_{b2}$) must be of the order of ninety volts or more to light an indicator bulb. %

The maximum alloweable current for a type 6J6 is 15 ma. which would mean 60 ma. per decade. Eleven decades for use at frequencies below 100 kc/s were required, which indicated a prohibitive power supply requirement. At this point then it was decided to limit the current per decade to approximately 20 ma.

Several attempts were made at choosing values for some of the circuit variables and testing such circuits on a "bread-board". From the experience gained in these circuits it was found possible to design a BM to satisfy a given set of requirements which when actually hooked up gave tube voltages and currents to within 10% of the calculated values. Such results were quite satisfactory for our requirements.

It is noted here that from the knowledge gained in a few experimental trials, the quantity i_c could be equated to approximately $0.015i_b$ for sufficient accuracy.

% Note: - The only useful bulb for this application is type NE2 or NE51, both of which are rated at one-twenty fifth of a watt. The former has pigtail leads whereas the latter has a bayonet base.

Even though it was possible to design a BM to obey a reasonable set of static conditions, the triggering characteristics were found to be very inconsistent. Tests carried out on some sixty odd BM's showed upper frequency limits from 130 kc/s to 2.4 mc/s. Trigger pulses were obtained from a broadband amplifier feeding a cathode follower to provide square-topped pulses at a low internal impedance. This triggering source however provides pulses whose leading edge slope is directly proportional to frequency and as the development work on the BM was progressing, we were beginning to be aware that the pulse requirements were more stringent than originally estimated. Pulses as derived in the above manner could well have contributed to the inconsistent upper frequency limit mentioned above. Finally the idea of using a pulse standardizer of the monostable multivibrator (one-shot multivibrator) or blocking oscillator type was conceived. A circuit of the former type developed along the usual lines (15) was incorporated with the broadband amplifier. It produced pulses approximately 4 microseconds wide and of 180 volts amplitude at frequencies from 200 kc/s to 20 c/s. Such an arrangement contributed greatly to producing better triggering stability in the decades.

After much trial-and-error experimenting, a set of circuit parameters following the broad considerations as outlined above was finally found acceptable from

the standpoint of stability, triggering ability etc. It is curious to note that the resistors for the most sensitive BM produced were selected by the "by-guess-and-by-gosh" method. Being aware that we would have to build 44 BM's in the 11 decades it was necessary to choose resistances of values of which we had sufficient numbers!!!

Fig. 6 indicates four BM's connected as a decade together with the connections to the indicator lamps.

4. OPERATION OF A DECADE:

A chain of four BM's will carry out division of incoming pulses by 16 but this method of operation in the binary system is awkward and if some circuit arrangement could be found whereby 6 of the 16 counts would be lost we would have secured operation in the decimal system. The problem of the count loss can be obtained in two ways, and ease of indication lead to the choice made below.

Fig. 6 indicates the connections used in the decades constructed for the frequency measuring device. C is the coupling condenser between stages. Triode number 2 of BM_1 will have its voltage alternate from approximately 40 volts when it is conducting, to 140 volts when it is non-conducting. The resultant wave form is a square wave

of about 100 volts peak to peak. Coupling condenser C together with the effective resistance to the succeeding BM will differentiate the square wave. Only the "negative-going" pulses will trigger the succeeding stage. The succeeding BM's behave in a similar manner.

The problem of effecting a loss in count of six is solved by feedback loops from the plate of V_5 to the grid of V_4 (C_2 and R_6) and from the plate of V_7 to the grid of V_6 (C_3 and R_7).

The operation of the circuit can best be understood by referring to Fig. 7. Let us suppose that all the BM's have been placed in the state where the right hand triode is conducting. This is indicated by the circle under columns two, four, six and eight. On receiving the first pulse the conducting state changes from V_2 to V_1 and the plate potential of V_2 rises to produce a positive pulse. Therefore, nothing happens to BM_2. Pulse number 2, puts V_2 on, generates a negative pulse which triggers V_3 on. The process is straight-forward to the end of the action of the third count. When the fourth pulse arrives V_2 and V_3 are made conducting which triggers V_5 on. The plate voltage of V_5 decreases, which gives a negative pulse. Since V_5 is nearly in a full state of conduction the energy received via the feed-back loop C_2-R_6 puts V_3 on. This

process is the equivalent of a two-count loss and is the first step in reducing the count from 16 to 10.

A second feed-back action takes place when the sixth pulse is applied. BM_1 is tripped to the right and this trips BM_2 to the right. The negative pulse from V_4 trips BM_3 to put V_6 on and the negative pulse from it triggers V_7 on. Due to feed-back loop C_3-R_7, V_6 does not remain on but rather V_5 is triggered on. The action is equivalent to effecting a loss of count 4. The remainder of the pulses applied to BM_1 actuate the BM's in the normal manner.

The indication system could be carried out with one neon bulb on the left hand triode of each BM, but this could involve a certain awkwardness in interpreting the count. The system of lamps shown in Fig. 6 indicates the count directly. A combination of three voltages from the plates of three appropriate triodes is used to produce conduction in each of the ten indicators. One of these voltages is taken at the junction of R_4 and R_5. This determines whether an odd or even count should be shown. The other two voltages are taken in five combinations from the other three stages.

For the indication of zero, all the right hand triodes are on. The upper terminal of the zero lamp is connected by way of a resistor to the left hand plate resistor of BM_1. This places a relatively high potential

on the upper side of the lamp. The lower terminal of the zero lamp is connected by way of two separate resistors to the right hand triodes of BM_2 and BM_4. These points are both at relatively low potential so that the resulting potential across the zero lamp is great enough to fire it and keep it on. Each lamp in turn operates on a combination of one high voltage and two low voltages.

5. FURTHER CONSIDERATIONS ON DECADE DEVELOPMENT

As the development on the decade was progressing it became more and more apparent that producing a decade to operate at ten megacycles introduced many complex problems. One of the main problems is to obtain a pulse standardizer at these frequencies. It is very difficult to produce a monostable multivibrator which will generate pulses shorter than three microseconds but the possibility of using a blocking oscillator appears interesting for it is known that pulses of the order of 0.05 microseconds wide and at a pulse repetition frequency of one megacycle per second can be produced with standard types of blocking oscillator transformers. However this is still a long way from ten megacycles per second, and it appears that the only method left is to use a broad-band amplifier to get as great an amplitude as possible and then to clip with germanium diodes. These have the advantage of very low capacities-a factor which is very important at the high frequencies.

In view of the above, it was decided to focus attention on five decades for use at 100 kc/s and below for the counter and six more for the crystal dividing circuit. Therefore the development work for the two high frequency decades for use from 100 kc/s to 1 mc/s, and 1 mc/s to 10 mc/s was suspended. However a number of ideas obtained while developing the low frequency decades are presented for possible use in the high frequency units.

5.1 TUBES FOR HF OPERATION

The choice of tubes for a BM appears to be of great importance. Tubes with high inter-electrode capacitances do not lend themselves to generation of fast waveforms. A number of investigators have used pentodes for BM's of the type 6AS6, but this does not appear to be a standard tube for sale to the public for it is not listed in the R.C.A. Tube Handbook. Other tubes with promising possibilities are the double triode types 12AU7 and 2C51 (5670). The latter has an electrostatic shield inserted between the two triodes, and has been incorporated in Loran equipment, type AN/APN9A produced by Radio Corporation of America, for division of the 100 kc/s crystal to produce pips or markers for the indicator unit.

The use of pentodes seems to be a wise choice because of their high input inpedance and the possibility of using the screens as the controlling electrodes for

putting either tube in a BM in an on or off state. This leaves the conventional control grid for use to introduce the triggering pulse as suggested by Regener (7).

When the low frequency decades were being constructed it was noted that not all tubes behaved similarly. In fact some brand new tubes refused to operate at all, even though such tubes operated quite well in other circuits as clamps or cathode followers. This observation was confirmed by United States Army Air Force personnel based at the Edmonton station in connection with American Loran installation.

Plate triggering is used in the low frequency decades and as mentioned above requires negative pulses. However this method of triggering requires pulses of the order of 60 volts or so. If triggering is done at the grids the pulse amplitudes can be much smaller. Further the use of biased diodes in the grids of the BM as suggested by Bliss (12) provides but one path for the energy rather than two or three as in the plate triggering methods. This conserves the energy of the triggering pulse for use where it was intended.

The operation of a BM is not very good when it must operate into a load. The effects may be either a reduction in the upper frequency limit or even cessation of division by two altogether. A number of solutions may

be possible here, the first of which is coupling between BM's with a pentode used as a cathode follower. Two advantages will be gained. The input impedance of a pentode is much greater than that of a triode and as a result the load placed on the BM feeding it will be very small. Its use as a cathode follower will then provide a low impedance source for the following stage.

5.2 FEEDBACK DIFFICULTIES:

In the development of high frequency decades difficulties are encountered in getting proper feedback to get division by 10. If we refer to Fig. 7 again, one may wonder why at the sixth pulse when BM4 keeps V_5 of BM3 on, the process does not continue as at the fourth pulse and put V_3 of BM2 on. If such a process happens we get division by eight. Actually four BM's in a chain have been used successfully up to 2.3 mc/s for division by sixteen. Either of the two feedback loops when used alone produces division by twelve as should happen. When both are used however, no matter what values of C and R are used in the feedback loops, the system divides by eight as outlined above. A theoretical solution to this problem has been evolved but not tried as yet. Referring to Fig. 8, this involves the return of a small amount of energy from the plate of either V_7 or V_8 to V_3 or V_4 as the case may be,

depending on the polarity desired. This will have the effect of cancelling the action of the plate voltage of V_5 at the sixth pulse. To prevent the application of a reversed pulse as would be produced by BM4 at the tenth pulse, diodes will have to be introduced in this feedback loop to obtain unidirectional flow.

An alternate solution to the above problem is the use of other systems of feedback between the various BM's. Fig. 9 shows a possible arrangement (27).

5.3. FURTHER POSSIBILITIES:

In addition to the above methods of developing HF decades mention is made here of a few additional possibilities.

The seven resistors and two condensers which are associated with every BM occupy a good deal of space and a possible solution may be found in printed circuits. Such a circuit was brought to the attention of the writer in the Loran equipment mentioned above. The cartridge consisting of the seven resistors and the two condensers was about $1\frac{1}{4}$ inches square and about $\frac{1}{8}$ inch thick with eight pigtail leads coming out. This together with one tube (type 2C51) comprised the complete BM.

Another possible circuit which may be tried incorporates compensating inductances in the plate leads to function much in the manner as in video amplifiers -

i.e., helping to cancel out the effects of the interelectrode and wiring capacitances (12).

The use of biased diodes or "DC clamps" has been suggested (26) as a means of speeding up a BM. The idea here is that once the triggering action has started, much time is lost in letting the action complete itself. The restrictive action of the clamps limits the grid voltage swing.

6. DESCRIPTION OF OTHER CIRCUITS:

The work entailed in developing this frequency measuring device has been done jointly by the writer and H. H. Dofka. The latter has been charged with the development and construction of the gate circuit, bridge-stabilized oscillator, and the frequency multiplier. This work is to be presented as a thesis at a later date, but it must be noted here that some of his work on the development of the decades is included in this report for reasons of better presentation.

6.1 BROADBAND AMPLIFIER:

Fig. (10) shows the broadband or video amplifier which has been selected for this instrument (20). The large band desired necessitated shunt and series peaking. The characteristics as stated in the above reference are as follows:

Input signal	1.2 volts
Output signal	-40 volts
Power supply	300 volts at 85 ma
Rise time	0.03 microseconds
Time for 10% droop	1000 microseconds
Band-width	12 mc/sec.

Shunt peaking alone in a video amplifier can be used to advantage for frequencies up to three or four mc/s, but if greater bandwidths are desired this method of compensation gives gains per stage approaching one. This is uneconomical from the standpoint of tubes used and series peaking must be introduced. However this results in more complex circuit problems and in problems of constructional design. Methods of analysis have been developed (21) but much trial and error work must be done to arrive at a satisfactory design with the required bandwidth. It is therefore probable that this circuit chosen from the literature is not of the optimum design.

The monostable multivibrator (one-shot multivibrator) has been designed following standard procedures (15) and its output pulse is approximately four microseconds wide.

To extend the range of this instrument to 10 Mc/s a pulse standardizer of the blocking oscillator will have to be developed.

6.2 RECEIVER:

The receiver used for checking the crystal frequency against WWV on ten megacycles per second was a standard fixed frequency air-to-ground type F3 produced by Wilcox Electric Co. It can be mounted in a standard 19" rack and is $3\frac{1}{8}$" high. The local oscillator is crystal controlled to give stable operation.

6.3. POWER SUPPLY

Fig. 11, shows the connections for the power supply to be used in the frequency measuring device. It has been designed to accommodate all the power requirements of this instrument. Beginning on the right a Hammond transformer type H-710 feeding two 5U4G's whose plates are connected in parallel is used to supply power to all the decades with the exception of the high frequency units. Only one choke type H-300X serves here to filter the output of the rectifier to the decades. Power to supply the bridge-stabilized oscillator is taken from this supply and passed through a second choke (5071) to provide a DC source with less ripple.

The second power supply from the right is well-filtered with two H-150X chokes to provide ripple-free power for the broad-band amplifier.

The third supply provides power for the gate circuit and two high frequency decades when these have been developed. A pi-section filter is used here to provide high output voltage.

Four type KS-9907 transformers are used to provide filament power for the whole instrument. The output of each transformer is rated at 6.3 volts at 10 amperes. Transformer H-1128 is used to supply power to the crystal oven which required 6.3 volts at 2.5 amperes. The pilot bulbs are also fed by this transformer.

7. OPERATION OF UNITS

The remainder of the circuits are to be described in the thesis submitted by H. H. Dofka and it is only there that a report on the operation of this device as a unit can be submitted. With regard to the circuits developed by the writer, their operation can in general be stated only in a qualitative manner. This is particularly true for the power supply.

The video amplifier has not been constructed in its final form and consequently the operating characteristics can only be stated in tentative form. The characteristics of this amplifier as constructed at the MIT Radiation Laboratory have been stated above.

With regard to the decades these either divide by ten or do not. Of the eleven which have been built all of them have been successfully adjusted for stable operation over a range of 225 kc/s to 20 c/s. However some difficulty has been experienced in getting the decades to operate properly in series and it is possible that the feedback circuits may have to be altered to correct this. It can be stated here that the stability of these units is not entirely satisfactory as yet for use in a reliable frequency measuring device.

However, the writer is confident that the original idea of measuring frequency by counting the cycles for one second has been proven to be entirely feasible, for the development of most of the other important circuits has been completed and the observations made here show that the desired results can be attained.

8. ACKNOWLEDGEMENT

The writer is most sincere in expressing his thanks to Prof. Porteous who has shown untiring interest in the development of the decade circuit. Further the writer thanks the Administration of the University of Alberta for granting financial assistance under the

General Research Fund to the amount of $350.00 for the purchase of parts. Research along these lines would have been impossible without this help. Thanks is also due to H. H. Dofka who contributed his ideas so freely in the development of the circuits described above.

9. REFERENCES

Note: All references shown below have not necessarily been noted in the body of this report but are included here for completeness.

1. Harry R. Meahl, "How accurately can time be measured ?" Gen. Elec. Review, Vol. 52, No. 2, pp 46-48 February, 1949.

2. L. A. Meacham, "High Precision Frequency Comparisons", Bell Lab. Record, Vol. 20, No. 7, pp 179-182, March, 1942.

3. H. B. Law, "An Instrument for Short-Period Frequency Comparisons of Great Accuracy", J.I.E.E., Vol 94, Part 3, No. 27, pp 38-41, January, 1947.

4. General Radio Co., "Catalogue L", pp 159-181, 1948.

5. J. K. Clapp, "Continuous Interpolation Methods", General Radio Experimenter, Vol. 18, No. 8 & 9. January and February, 1944.

6. L. A. Meacham, "The Bridge Stabilized Oscillator", P.I.R.E., Vol. 26, No. 10, pp 1278-1294, October, 1938.

7. Victor H. Regener, "Design and Use of Directly Coupled Pentode Trigger Pairs", Rev. of Sci. Instr., Vol. 17, No. 5. pp 180-184, May 1946.

8. Victor H. Regener, "Decade Counting Circuits", Rev. of Sci. Instr., Vol. 17, No. 5 pp 185-189., May, 1946

9. Victor H. Regener, "Reversible Decade Counting Circuit", Rev. of Sci. Instr. Vol. 17, No. 10, pp 375-376, Oct. 1946.

10. W. H. Eccles, and F.W. Jordan, "A Trigger Relay Utilizing Three-Electrode Thermionic Vacuum Tubes" Radio Review 1, 143, 1919. (Not available in University Library).

11. I. E. Grosdoff, "Electronic Counters", RCA Review, Vol. 7 No. 3, pp 447, Sept. 1946.

12. Warren H. Bliss, "Electronic Digital Counters", AIEE, Vol. 68, No. 4, pp 309-314, April 1949.

13. Leo Seren, "Decade Ring Scaling Circuit", Rev. of Sci. Instr., Vol. 18, No. 9, pp 654-659, Sept. 1947.

14. Radiation Laboratory Series, Vol. 19, "Waveforms", Chance et al, pp 174-177, McGraw-Hill,

15. MIT Radar School Staff, "Principles of Radar" 2nd edition, pp 2-53 to 2-58, McGraw-Hill.

16. C.B. Leslie, "Megacycle Stepping Counter", P.I.R.E., Vol. 36, No. 8, pp 1030-1034, August, 1948.

17. R.L. Chase, "Measuring a Varying Frequency", Electronics, Vol. 23, No. 3, pp 110-120, March, 1950.

18. United States Atomic Energy Commission - "A proposed method of counting voltage pulses less than 0.1 microsecond long at a continuous rate of more than 10 megacycles" Watkins, Report, No. AECU-79.

19. United States Atomic Energy Commission, "A High-Speed Scaler Design", Johnstone Report No. AECU-364.

20. Radiation Laboratory Series, Vol. 22, "Cathode Ray Tube Displays", Soller et al. pp 731-735, McGraw-Hill.

21. Radiation Laboratory Series, Vol. 18, "Vacuum Tube Amplifiers" Valley, et al. pp 76-77, McGraw-Hill.

22. A. E. Wolfe and F. G. Steele, "Direct Reading Electronic Clock", Electronics, Vol. 22, No. 12, pp 75-77, December, 1949.

23. C. H. Page, "Digital Computer Switching Circuits", Electronics Vol. 21, No. 9, pp 110-118, September, 1948.

24. T. K. Sharpless, "High Speed N-Scale Counters", Electronics, Vol. 21, No. 3, pp 122-125, March 1948.

25. Arthur W. Blake, "Electronic Computing Circuits of the ENIAC", P.I.R.E., Vol. 35, No. 8, pp 756-767, August, 1947.

26. Radiation Laboratory Series. Vol. 19, "Waveforms" Chance, et al. pp 605 et seq., McGraw-Hill

27. Tracerlab pamphlet "Tracerlog" No. 21 September, 1949

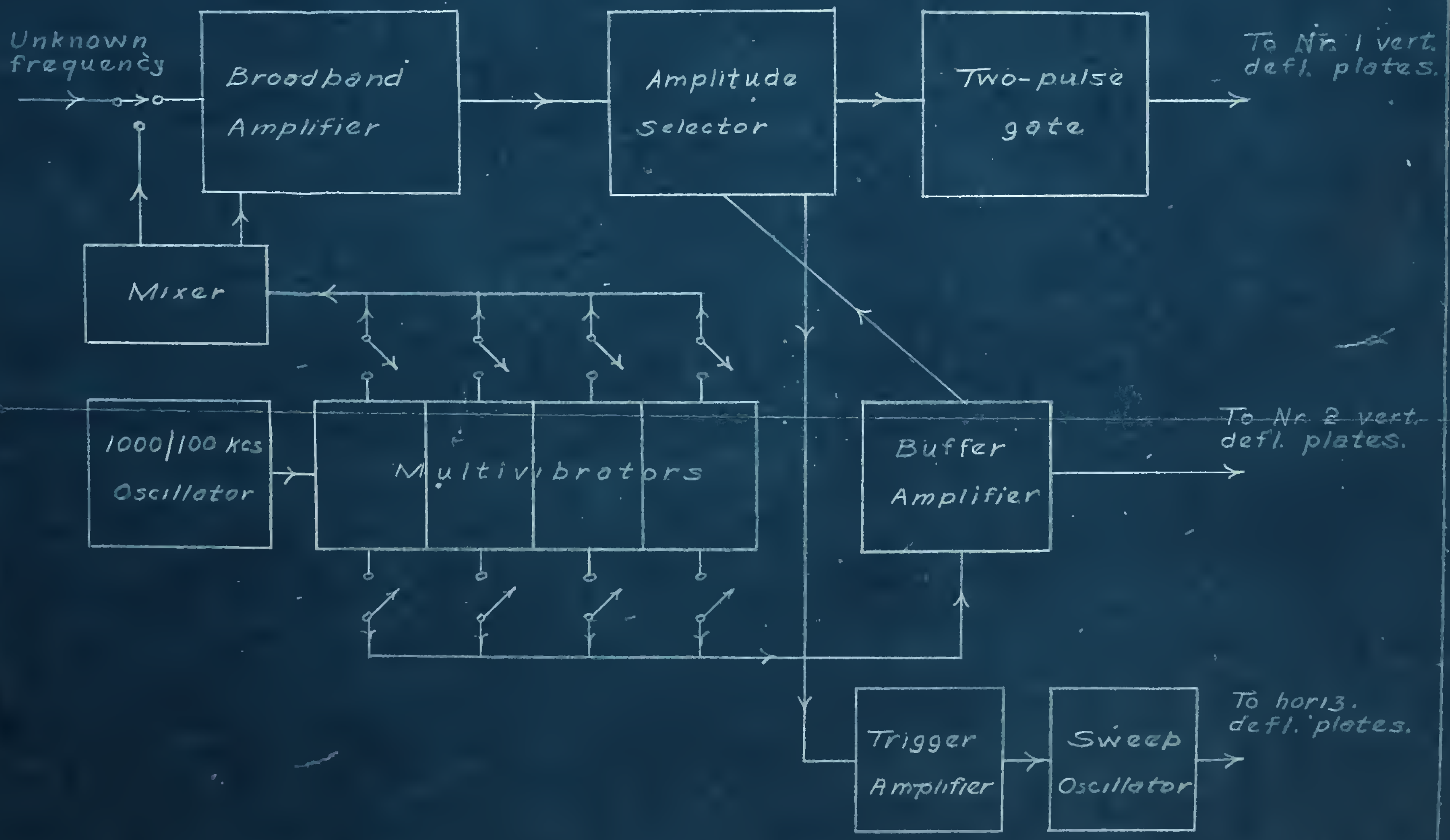

Unknown frequency
Broadband Amplifier
Amplitude Selector
Two-pulse gate
To Nr. 1 vert. defl. plates.
Mixer
1000/100 kcs Oscillator
Multivibrators
Buffer Amplifier
To Nr. 2 vert. defl. plates.
Trigger Amplifier
Sweep Oscillator
To horiz. defl. plates.

FIG. 1.

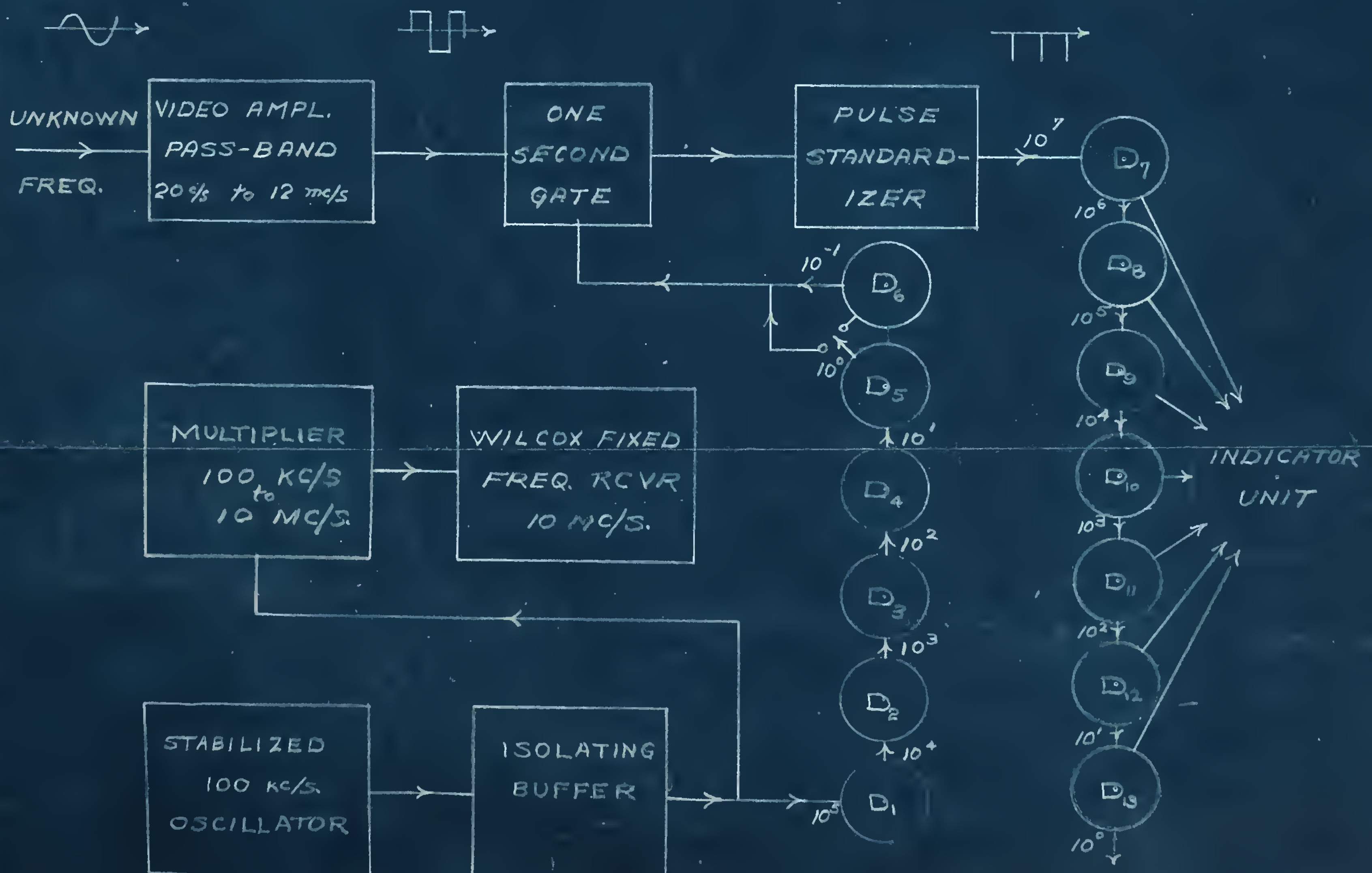

UNKNOWN FREQ.
VIDEO AMPL. PASS-BAND 20 c/s to 12 mc/s
ONE SECOND GATE
PULSE STANDARD-IZER
10^7
D_7
10^6
D_8
10^5
D_9
10^4
D_{10}
10^3
D_{11}
10^2
D_{12}
10^1
D_{13}
10^0
INDICATOR UNIT
10^{-1}
D_6
10^0
D_5
10^1
D_4
10^2
D_3
10^3
D_2
10^4
D_1
10^5
MULTIPLIER 100 KC/S to 10 MC/S.
WILCOX FIXED FREQ. RCVR 10 MC/S.
STABILIZED 100 KC/S. OSCILLATOR
ISOLATING BUFFER

FIG. 2.

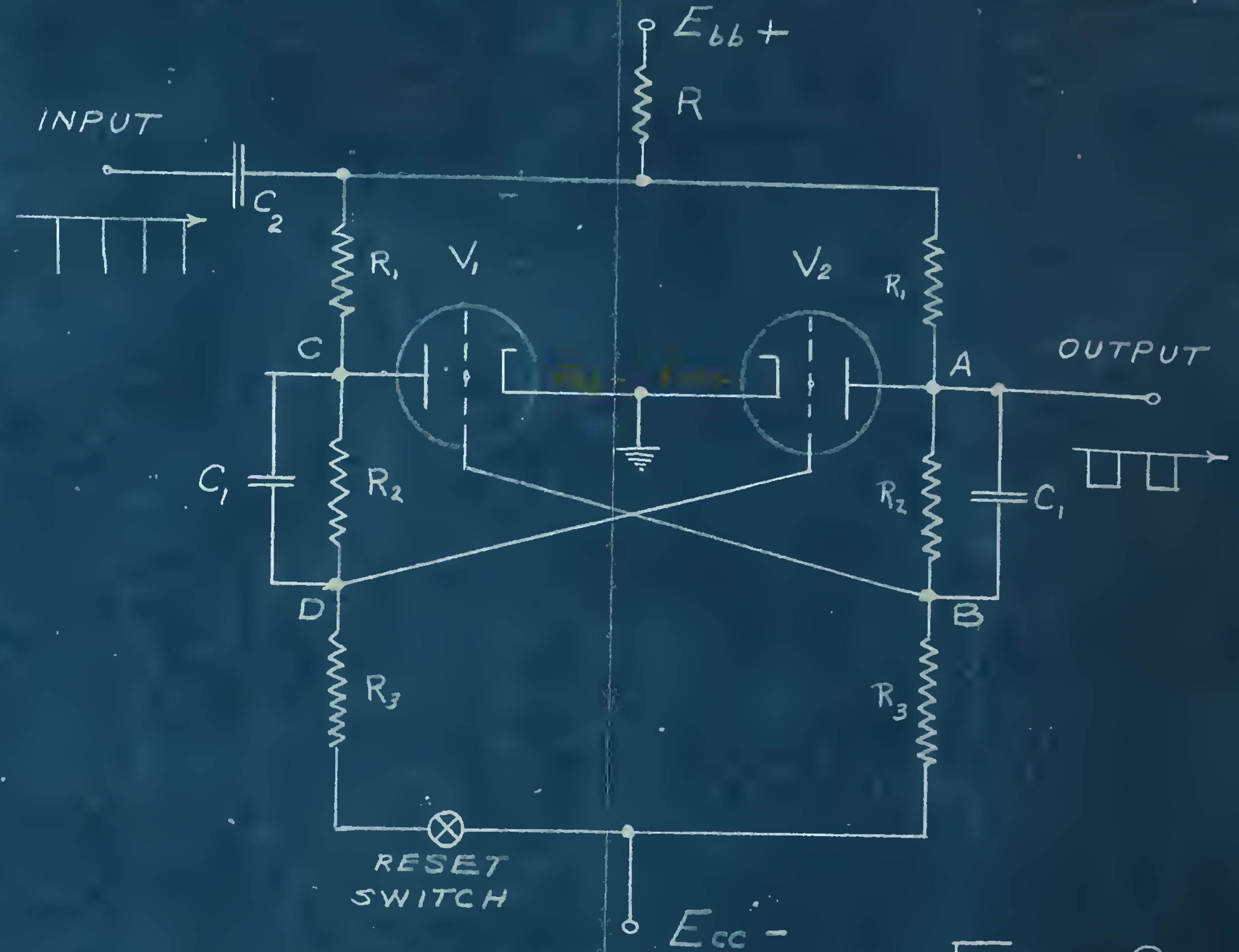

E_bb +
R
INPUT
C_2
R_1
V_1
V_2
R_1
C
A
OUTPUT
C_1
R_2
R_2
C_1
D
B
R_3
R_3
RESET SWITCH
E_cc -

FIG. 3.

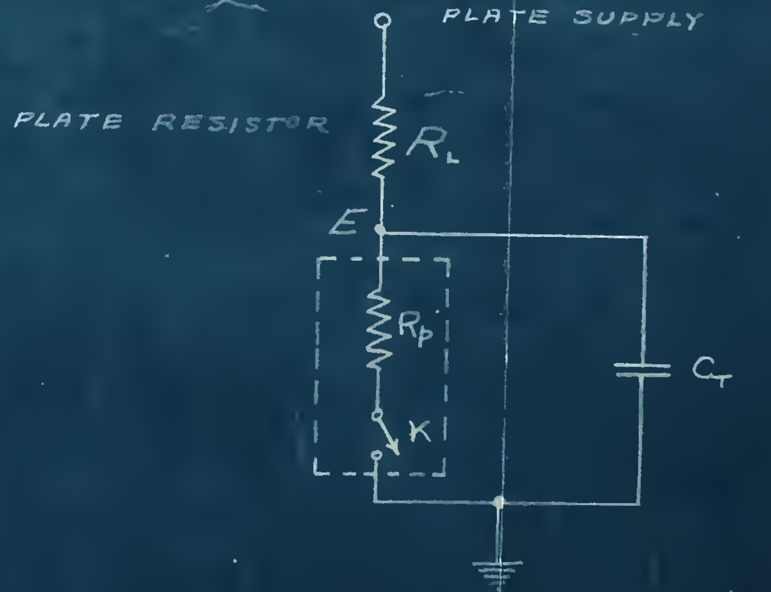


PLATE SUPPLY
PLATE RESISTOR
R_L
E
R_p
K
C_T

FIG. 4.

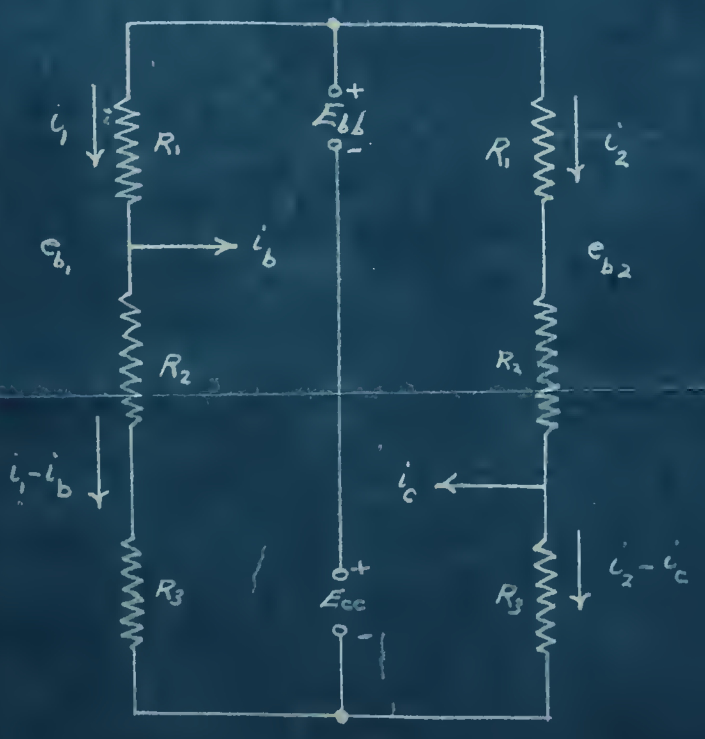
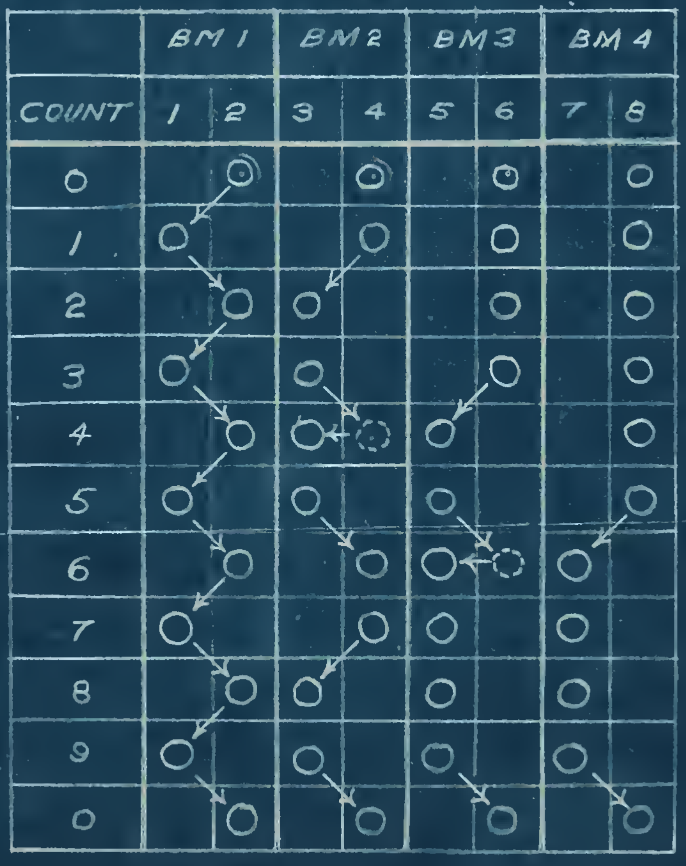


FIG. 5.



	BM 1		BM 2		BM 3		BM 4	
COUNT	1	2	3	4	5	6	7	8
0		⊙		⊙		⊙		○
1	○			○		○		○
2		○	○			○		○
3	○		○			○		○
4		○	○	◌	○			○
5	○		○		○			○
6		○		○	○	◌	○	
7	○			○	○		○	
8		○	○		○		○	
9	○		○		○		○	
0		○		○		○		○

FIG. 7.

$R = 15K$ 1W

$R_1 = 30K$ 1W

$R_2 = 100K$ 1W

$R_3 = 15K$ $\frac{1}{2}$W

$R_4 = 15K$ $\frac{1}{2}$W

$R_5 = 15K$ $\frac{1}{2}$W

$R_6 = 100K$ $\frac{1}{4}$W

$R_7 = 100K$ $\frac{1}{4}$W

$R_8 = 500K$ $\frac{1}{2}$W

$R_9 = 1K$ pot

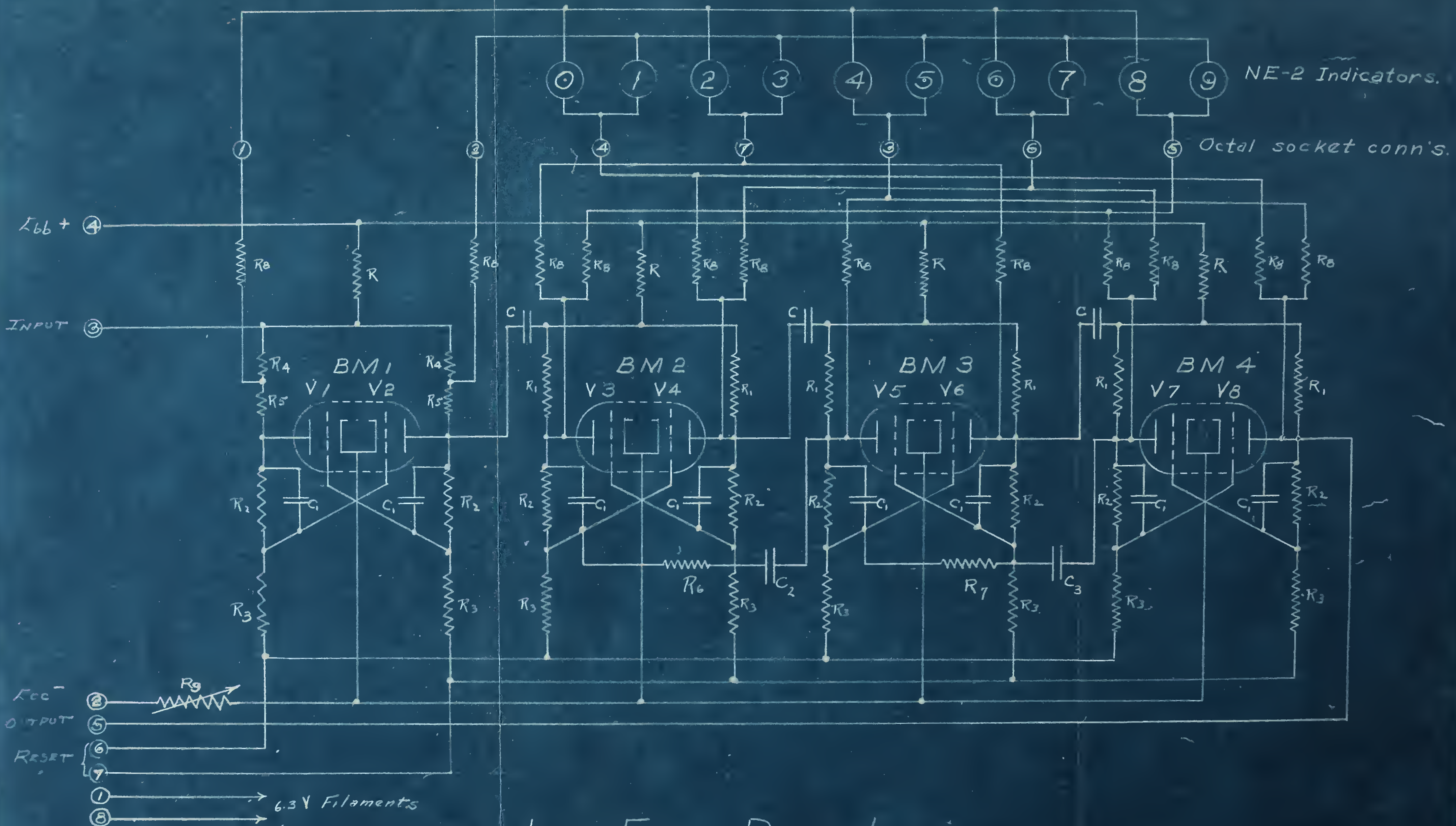
$C = 10$ μμf

$C_1 = 25$ μμf

$C_2 = 10$ μμf

$C_3 = 10$ μμf

ALL TUBES TYPE 6J6.



Low-Freq. Decade.

FIG. 6.

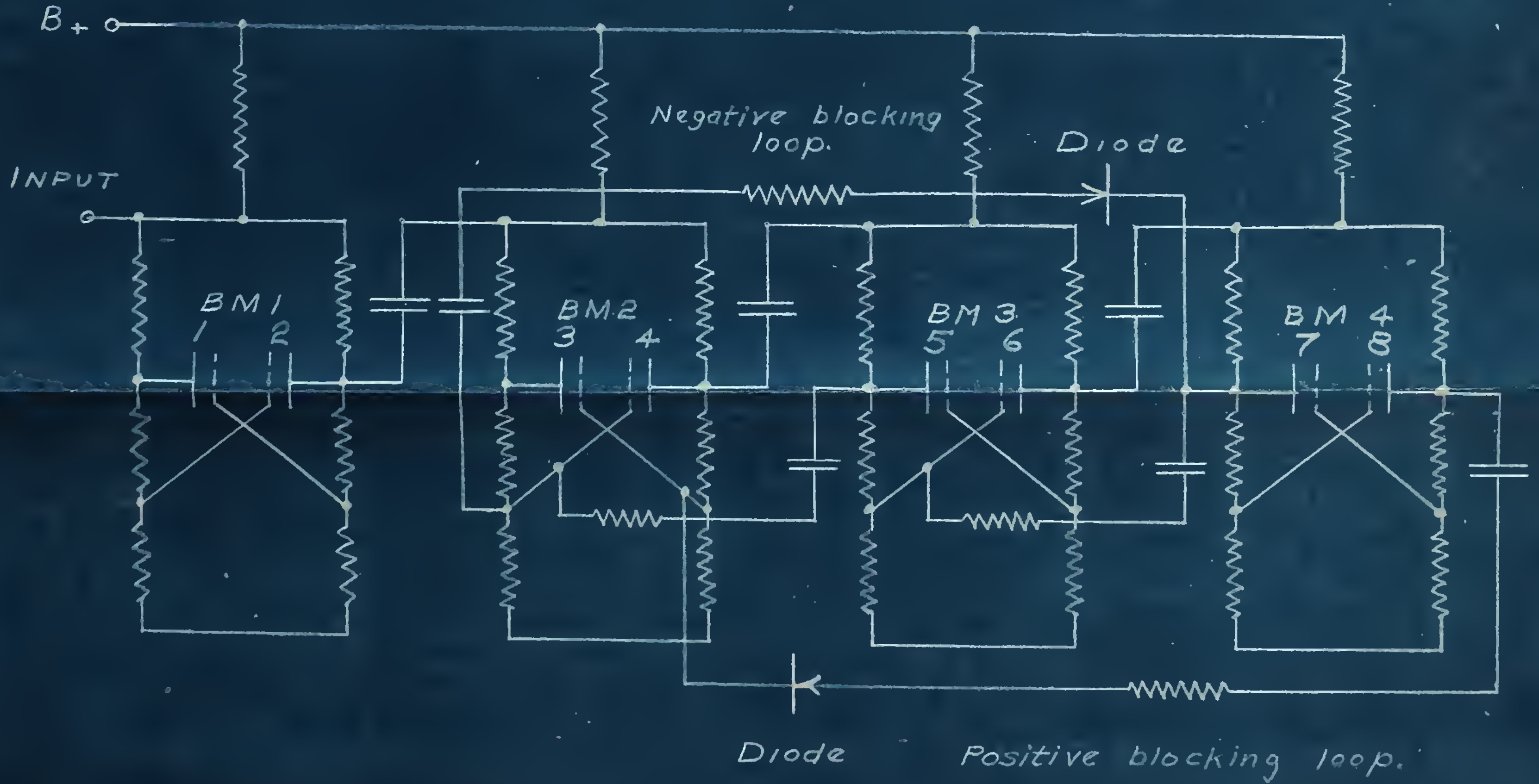
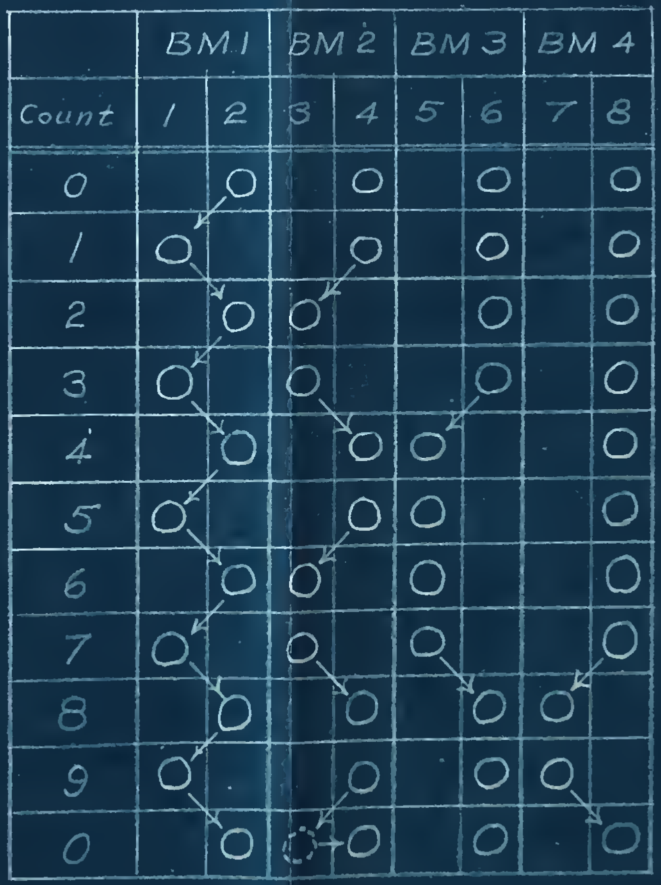

B+
INPUT
BM 1
1
2
BM 2
3
4
Negative blocking loop.
BM 3
5
6
Diode
BM 4
7
8
Diode
Positive blocking loop.

FIG. 8.

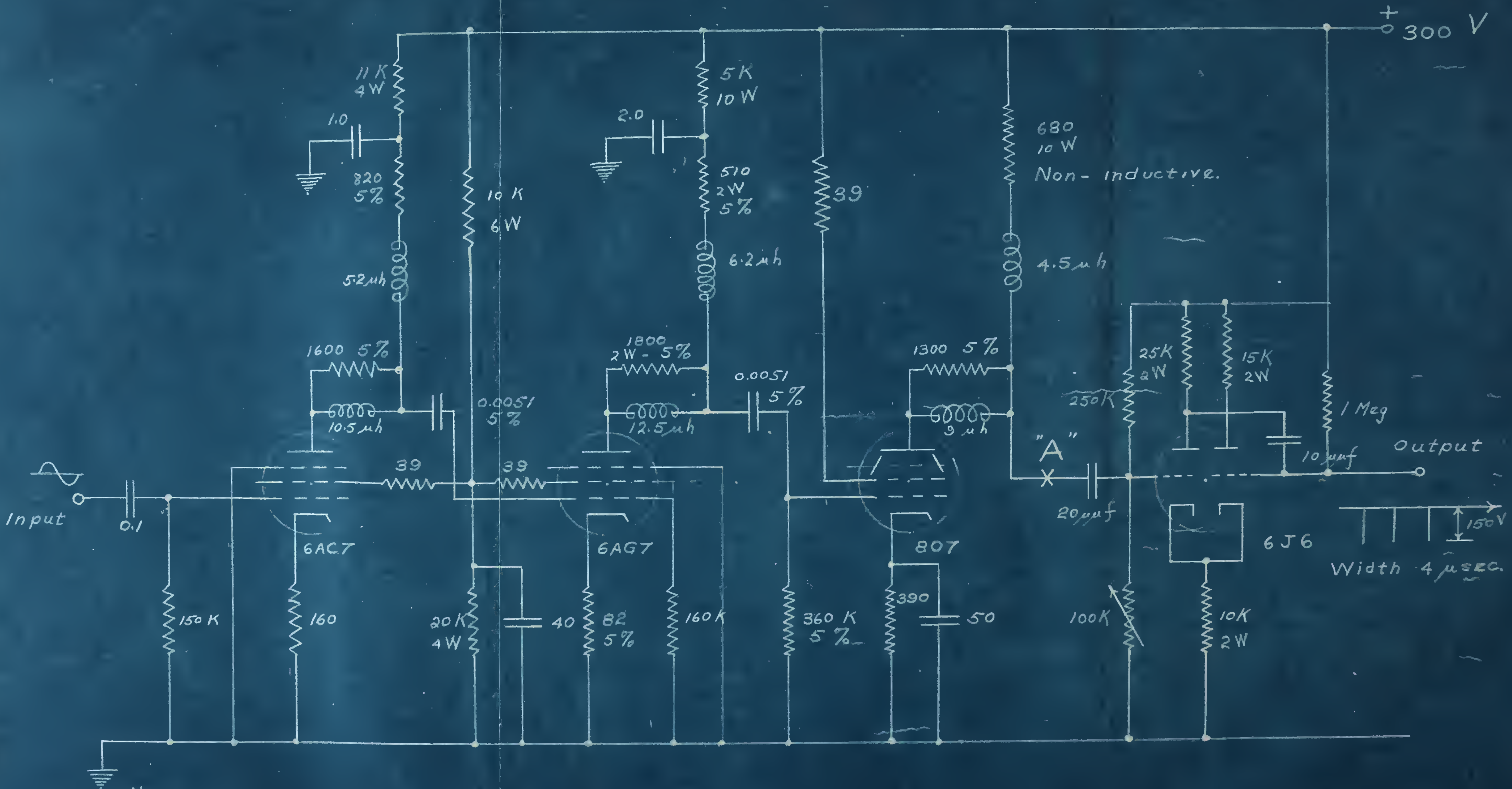
Alternative Decade System



	BM 1		BM 2		BM 3		BM 4	
Count	1	2	3	4	5	6	7	8
0		○		○		○		○
1	○			○		○		○
2		○	○			○		○
3	○		○			○		○
4		○		○	○			○
5	○			○	○			○
6		○	○		○			○
7	○		○		○			○
8		○		○		○	○	
9	○			○		○	○	
0		○	○	○		○		○

Plate of [illegible] to grid of 7 and
Plate of 5 to grid of 3.

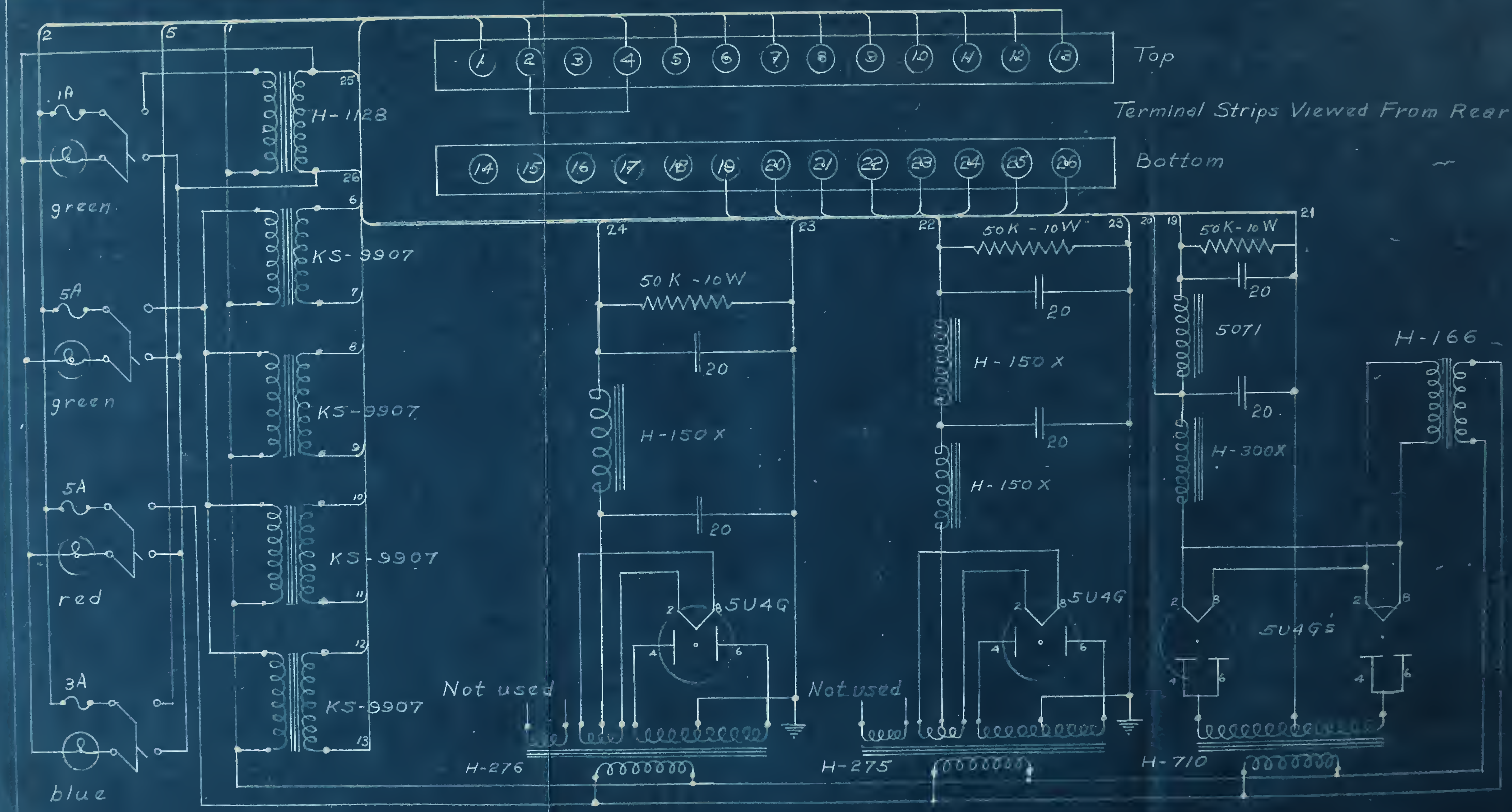
Fig. 9.



NOTES:-
1. All resistances ½ W unless otherwise indicated.
2. All capacitances in microfarads.
3. Gate circuit to be inserted at "A"

Broadband Amplifier

FIG. 10.



Note:-
1. Hammond components are indicated H- .
2. Transformers KS-9907 are War Surplus.
3. Terminals 4+5 are for Wilcox Rcvr.

FIG. 11.

B29759